Re-assessment of Mountain Pygmy-possum *Burramys parvus* population size and distribution of habitat in Kosciuszko National Park

L. Broome[1], F. Ford[2], M. Dawson[3], K. Green[4], D. Little[1], N. McElhinney[5]

[1] Office of Environment and Heritage, P.O. Box 733 Queanbeyan, NSW, 2620

[2] Estate Policy and Environment Branch, Defence Support Group, PO Box 7925, Canberra BC, ACT 2610

[3] Eco Logical Australia Pty. Ltd., 62 Moore Street, Austinmer, NSW 2515

[4] Snowy Mountains Region, National Parks and Wildlife Service, P.O. Box 2228, Jindabyne, NSW 2627

[5] Division of Resources and Energy, NSW Trade and Investment, PO Box 344, Hunter Regional Mail Centre, NSW 2310

Corresponding author: linda.broome@environment.nsw.gov.au

ABSTRACT

The New South Wales population of the Mountain Pygmy-possum *Burramys parvus* was estimated at 500 adults in 8 km^2 of boulder-heath habitat during surveys in the 1980's. In 1989, this estimate was increased to 1312 adults based on further surveys in four of the identified habitat patches. However, further research indicated that population density varied greatly between habitat patches and that the original extent of habitat and the revised population estimate had been overestimated. Because of the high degree of uncertainty regarding the total population size of *B. parvus* in New South Wales and the relative value of each habitat patch, including those in ski resorts, it was necessary to re-evaluate these estimates. Results based on data collected between 1996 and 2001 indicated an adult population of around 613±92 in 1.85 km^2 of boulderfield habitat. This population was distributed in scattered colonies within a modelled bioclimatic range of 444 km^2 of suitable climate, based on modelling of the then known southern Kosciuszko *B. parvus* population. However the notional extent of suitable climate has been greatly enlarged by the recent discovery of a northern Kosciuszko population. Establishing which boulderfields to target for future surveys within the enlarged potential climate envelope is not simple. No strong association with any habitat characteristics were identified by habitat analysis, however, deeper boulderfields with a variety of boulder sizes and reasonable vegetation cover were generally preferred. Changes in habitat characteristics across the elevational gradient partly explained the difficulty in modelling habitat preference.

Key words: Mountain Pygmy-possum, *Burramys parvus*, Kosciuszko, Bogong Moth, habitat assessment

http://dx.doi.org/10.7882/AZ.2013.009

Introduction

The Mountain Pygmy-possum *Burramys parvus* is a small (35g), terrestrial burramyid marsupial. Described from fossil remains (Broom 1896) it was first discovered as an extant species when found in a ski lodge in Victoria in 1966 (Anon 1966a, b) and first caught in New South Wales in Kosciuszko National Park in 1970 (Calaby *et al.* 1971). Surveys in the early 1970's and 1980's indicated populations were largely confined to patches of boulder-dominated habitat and associated shrubby heathland in the Australian Alps from Mt Bogong to Mt Hotham in Victoria and in southern Kosciuszko National Park in New South Wales (Calaby *et al.* 1971, Gullan and Norris 1984, Caughley 1986, Mansergh *et al.* 1989).

Caughley (1986) sampled a range of heath types in Kosciuszko National Park above 1500 m elevation with and without boulders. The majority of *B. parvus* was caught in rocky areas with a diverse association of shrubby heath that included Mountain Plum-pine *Podocarpus lawrencei*. The total population size of *B. parvus* was estimated at around 2000 individuals, which included some 500 adults. Caughley's estimate was based on an average density of 2.6±1.7 *B. parvus* per hectare, with an adult to juvenile and male to female ratio of around 1:3 (i.e., adult density 0.65/ha), in approximately 8 km^2 of habitat. This estimate was derived from 10 survey sites each sampled for 3 nights between February and April during a full moon which, Caughley argued, sampled the majority of the trappable population. At the time of Caughley's surveys it was not known that *B. parvus* adults begin to hibernate as early as late February and most individuals are hibernating by late April.

Broome (1992) obtained average densities (between November and March) of two to three times Caughley's estimates in four of the areas previously used to derive estimates. Using a comparison of the most reliable data set (from Mt Blue Cow 1986 - 1989), Caughley's estimate was multiplied by a factor of 2.27 to produce a revised estimate of 1312 adults in New South Wales (327 males: 985 females) (Broome and Mansergh 1989). However, subsequent trapping by Broome in several additional areas surveyed by Caughley (1986) suggested that the four sites monitored by Broome (2001a), and one additional site on Mt Kosciuszko appeared to have high abundance of *B. parvus* (average density 11.05 adults/ha) compared to many of the other sites within the alpine area. The relative value of such sites would be underestimated by assigning an average density to them, and equally, applying densities derived from them to the total 8 km^2 of habitat mapped by Caughley (1986) would inflate the total population estimate.

Much of the habitat mapped by Caughley (1986) was identified from high level (1:24,000) aerial photographs. Preliminary ground truthing between 1986-1996 indicated that some of these areas were quite unsuitable for *B. parvus* and suggested that the extent of habitat had also likely been over-estimated. However, it appeared there may also be additional sites, for example, north of the air photo coverage near Gungartan, that were not included in Caughley's estimate. Because of the high degree of uncertainty regarding the total population size of *B. parvus* in Kosciuszko National Park and the lack of knowledge concerning the relative value of each habitat patch, including those within ski resorts, it was necessary to re-evaluate these estimates. The aim of this study, conducted between 1996-2001, was to re-trap and survey habitat areas identified by Caughley (1986), identify and survey additional sites, and assess habitat characteristics, population abundance and density to produce a revised population size estimate and habitat map for *B. parvus* in New South Wales (Broome *et al.* 2005). However in 2010-11 three new colonies of *B. parvus* were discovered near Cabramurra, well to the north of the area considered in the original study, and outside the predicted area of suitable climate based on the southern colonies alone (Schulz *et al.* 2012a, Broome, Bates and Shi unpubl. data). Climatic predictions were therefore re-run to examine the implications of this discovery for the enlarged NSW distribution of *B. parvus*.

Methods

Identification of habitat and trapping of B. parvus

Breeding populations in boulderfields (technically periglacial blockfields, blockstreams, moraines, or solifluction deposits, Rosengren and Peterson 1989, Galloway 1989, or tors and boulder scatters around rocky summits) were targeted for trapping between November and mid-December. *Burramys parvus* breeds at one year of age, and unless the first litter is lost, usually have one litter per year (Mansergh and Scotts 1990, Broome 2001b, Heinze *et al.* 2004). Broome (2001b, unpubl data) found that the highest numbers of adults were trapped early in the breeding season in November-December and that populations were concentrated around well-defined boulderfields at this time of year. Lactating females suckle young in the nest during late December to January, and frequent trapping during this period may affect the survival of young. Dispersal occurs between February and April. Adult males and a high proportion of juveniles, especially males, disperse and migrate from breeding sites to occupy surrounding areas of heathland where boulder patches are often small or dispersed (Mansergh and Scotts 1990, Broome 2001b, Heinze *et al.* 2004). These habitats are critical for the species, but are often difficult to delineate.

Boulderfields often occurred in clusters, and although a range of boulderfield types within each cluster were sampled, what was anticipated to be the best habitat in each cluster (based on previous field experience) was always trapped to maximise the number of individuals detected. As a population estimate was a primary aim of this study, larger boulderfields had a correspondingly higher number of traps. However, density of trapping effort was relatively constant. Broome (2001b) found that *B. parvus* individuals frequently move distances of 500 m or more between boulderfields within a habitat cluster on a nightly basis. Therefore boulderfields less than 500 m apart that were on the same aspect were trapped and treated in the analysis as a single habitat unit. Trapping commenced in December 1996. Following helicopter reconnaissance of the sites identified by Caughley (1986) in June 1997 the bulk of remote sites were trapped between November and December 1997. Additional sites identified from aerial photos, or on the ground during trapping and habitat surveys were trapped between 1998 and 2001. For the four sites that were monitored each year (Broome 2001a, unpubl. data), a year between 1996 – 2001 was randomly chosen to provide data for this study.

Trapping was conducted for 3 or 4 nights at most sites. Traps at sites trapped for 3 nights were baited with walnuts. Traps at sites trapped for 4 nights were baited with chocolate[1] on the first night to enable collection of scats for dietary analysis that were unadulterated by bait. Walnuts were used on nights 2-4 to provide a preferred food source. *Burramys parvus* are easily trapped. Caughley (1986) conducted trapping over 3 nights during her surveys and found similar numbers of possums were trapped each night and no evidence of trap shyness or differential trappability between age or sex of animals. Trapping on the four sites monitored by Broome (2001a) was conducted over 3 nights between 1987 - 1994 and 4 nights from 1995 - 2001. Chocolate was not as attractive as walnut as a bait and fewer animals were generally caught on the first night when chocolate was used (Broome unpubl. data), however, results generally indicated that few additional animals were trapped on the third night of baiting with walnuts. Most survey sites trapped in the current study, apart from the long-term monitoring sites, had insufficient numbers of animals captured to estimate population size from capture-recapture models. However,

[1] The attractant of the chocolate bait appeared to be the smell and it was seldom ingested. When collecting scats we now use half a cotton make-up pad soaked with walnut oil as an attractant for the first night of trapping.

modelling on the four monitoring sites by Broome (2001a, unpubl.data) over the 15 years from 1987-2001 (using the heterogeneity model in program CAPTURE, White *et al.* 1978, 1982) usually indicated population closure (81% of 87 models), high capture probabilities and on average an 11% difference between the population size estimates (N-hat) and numbers trapped (N). Similarly the average difference between the population estimate ± 2 standard errors was 15%. In the current study, abundance and densities are derived from the numbers trapped, and a final adjustment is made to estimate population size by adding 11 %, the average difference between N and N-hat on the monitoring sites.

Mapping of habitat and measurement of habitat variables

All boulderfield patches were delineated on aerial photos enlarged to a scale of 1:2000 or 1:5000. These patches were ground-truthed during the trapping and habitat assessment surveys. Distortion in the aerial photographs was corrected by using reference co-ordinate points marked on the photography or by comparing the photographs with geometrically corrected satellite imagery. Digitised and geometrically corrected boulderfield polygons were stored as an ArcView Shapefile (Lourens *et al.* 2002). Eighty-four survey sites, including 186 of 605 digitised boulderfield polygons, were trapped and surveyed for habitat variables.

Elevation and aspect were determined for each site from a grid based digital elevation model (DEM) and aspect surface previously developed for Kosciuszko National Park. Percent snow cover was calculated as the percentage of each site covered by snow on each of 8 Landsat TM images taken between July and November 1996 and July and September 1998 (Lourens *et al.* 2002).

Measurement of a range of habitat variables at each of the trapping sites commenced in February 1998. Each site was assessed at a site level and at multiple plots within each site. Site level variables included slope, the quantity of visible Bogong Moths *Agrotis infusa* (ranked on a scale of 0-3 from absent to abundant), the distance to the nearest watercourse, whether watercourses within the boulderfield were absent, intermittent or permanent, continuity with other boulderfields (scaled 1-4 from completely isolated in grassland to well connected by other boulderfields and heath), a visual assessment of percentage vegetation cover, the percentage occurrence of 9 vegetation communities surrounding the boulderfield (to a distance of 20 m), a list of vegetation species present and a visually assessed complexity rating. Complexity was initially assigned a scale of 1-3 (little boulder structure and low vegetation cover and diversity to highly structured, deep boulders and good shrub cover) but this was changed to a scale of 1-5 during data preparation because many of the values given in the field fell between the categories (1-2 or 2-3). Plot level variables included percent cover of vegetation, substrate (% cover of rock and soil), shrub height (*Podocarpus* and other shrubs), % cover of eight key food plant species (Smith and Broome 1992) and grass, presence of all other plants (species for shrubs, categories for herbs e.g., *Ranunculus* spp., daisies, ferns etc.), the number of boulder layers (0=rock protruding from soil, 1=one layer – rock sitting on soil, 2=two layers - substantial rocks sitting on other rocks, 3 = three layers - more than 2 layers of rock but ground still visible and 4 - more than 3 layers, ground not visible), boulder depth (the vertical height from the ground surface to the average height of the top layer of boulders, if depth was indeterminable (generally greater than 1.5 –2 m) a maximum assessable value was determined and 50 cm was added for data analysis), ground visibility (scored 0 – no ground visible to 5 - ground only, no rock) and boulder size - the number of boulders in each of 5 size categories (<20 cm, 20-50 cm, 50-100 cm, 1-2 m, >2 m) that could be seen within or touching the plot. Plots were circular with a 1m radius. The number of plots was proportional to the size of the boulderfield, ranging from 10 on the smaller boulderfields to 90 on the large boulderfields. Plots were evenly spaced on the boulderfields following contours and extended 10 m beyond the edge to sample the surrounding habitat.

Climatic site profiles and distribution modelling

Thirty-five bioclimatic parameters were generated for each trapping site using the BIOCLIM module of ANUCLIM (Nix 1986). These were used in habitat regression models (below). The Kosciuszko 25 metre DEM was used to model five climatic variables (maximum temperature, minimum temperature, rainfall, radiation with rainfall and evaporation) using the twelve standard Australian climatic surfaces provided with ANUCLIM. A second climatic profile was produced for all sites where populations of *B. parvus* were recorded during this study. The BIOMAP module of ANUCLIM was used to produce a predictive map based on modelling of six variables; annual mean temperature, maximum temperature of warmest period, minimum temperature of coldest period, annual precipitation, precipitation of the wettest period. The full range (0-100) was considered the most appropriate measure as some of the largest known populations of *B. parvus* inhabit the highest peaks in Australia (Mt Kosciuszko and Mt Townsend), suggesting that the potential climatic distribution of the species extends well above the altitudinal availability of habitats.

Data analysis

Field collected habitat characteristics were measured both at the site level, and at multiple plots within each site. Those collected at multiple plots were reduced to single variables for each site, or, for characteristics with more than one measurement category, to summary statistics based around levels of measurement (e.g. percentage occurrence of three different boulder size classes across plots). Methods of reduction for each variable are listed in Table 1. Further reduction in the number of analysed variables was achieved via principal components analysis for boulder layers, boulder counts, vegetation cover, complexity and BIOCLIM attributes. The "complexity" variable was a loosely defined visual assessment of the diversity of vegetation and boulder structure present within a site. It was therefore not included in regression analysis. Various methods were attempted to reduce complexity of floristic data from the presence/absence of species at each site. However, the generally sparse and low diversity vegetation of boulderfields meant that no method identified any distinct patterns. For

Table 1. Methods used to reduce plot-based variables to site-based variables for analysis.

Variable	Initial measurement	Reduction method
% Vegetation	% at n plots	Classes: % plots <20%, 20-80%, >80%
Rock	% at n plots	Average for n plots
Soil	Not analysed: reciprocal of rock	
Height *P. lawrencei*	cm at n plots	Average for n plots
Height other shrubs	cm at n plots	Average for n plots
Boulder depth (cm)	cm at n plots	Average for n plots & %>1m
Visibility	Not analysed	
Boulder layers	Number of layers at n plots	Classes: % plots 0,1,2,3+ layers
Boulders: <20cm	Count at n plots	Average for n plots
20 - 50cm	Count at n plots	Average for n plots
50 - 100cm	Count at n plots	Average for n plots
1 - 2m	Count at n plots	Average for n plots
>2m	Count at n plots	Average for n plots
Cover key plants (each of 9 species)	% cover at n plots	Average for n plots

example, the best principal component of plant species occurrence explained only 19% of the variation, and only two explained more than 5%. A similar lack of clear pattern was obtained using multi-dimensional scaling. Plant species occurrence data was therefore represented in analysis only by floristic diversity. Variables included in regression models were; area (ha), aspect, average boulder depth, average % rock cover, average *Podocarpus lawrencei* height, average shrub height, average % snow cover, bioclim PC1, block-water course, Bogong Moth count, boulder count PC1, boulder count PC2, *B. parvus* presence, abundance and density, continuity, % cover of each of eight key food plants, grass, and all vegetation combined, elevation, floristic diversity, layers PC1and PC2, slope, surrounding proportion of snowgum woodland, tall heath, short heath, damp bog, raised bog, herb/grassfield, valley bog, fen and feldmark, vegetation cover PC1, water distance.

Interactions were expected between many variables; altitude and aspect in particular were expected to affect vegetation attributes and snow cover. Scatterplot matrices were used to identify correlated variables, and regression analysis was used to test the strength of relationships. Number of traps (and trap nights) were correlated with total possum captures (0.52), but not possum density (0.08) or detection of possums at a site (0.35). Ordinarily a correlation between number of traps and trapping success could indicate sampling bias or methodological problems. However, sites with less traps were smaller boulderfields, and could therefore not hold more traps. Intensity of trapping (traps/unit area) was not correlated with captures (-0.18). Some trapping "bias" is evident due to the monitoring grids, which are known to be large populations, and which contain some of the highest numbers of traps due to annual trapping programs. The correlation between trap success and number of traps was significantly lessened by excluding the four monitoring sites (0.35), and it is a reasonable assumption that the number of possums captured at survey sites was representative of the size of those populations at the time of the survey. Exploratory regression analyses or t-tests were used to identify variables that were most likely to influence presence, abundance (individuals/site) or density (individuals/ha) of *B. parvus*. The number and density of *B. parvus* and the more common small mammal species, Bush Rats *Rattus fuscipes*, Dusky Antechinus *Antechinus swainsonii* and Broad-toothed Rats *Mastacomys fuscus*, were positively correlated across the sampled boulderfields. Other small mammal captures were therefore not included in regression analyses, as it was thought that the correlations were likely due to similar needs for food resources and shelter and any direct interactions between possums and these species would have a negative effect on possums, rather than increasing their abundance.

Multiple regression analyses were performed in the generalised linear modelling module of Statistica 6 to determine what factors influenced; 1) presence of *B. parvus* in a boulderfield, 2) abundance of *B. parvus* within a boulderfield, 3) density of *B. parvus* within a boulderfield. Variables included in models were those identified in exploratory analysis as being potentially different between sites with and without *B. parvus*, and those that exhibited reasonably strong correlation with the abundance or density of *B. parvus*. Models initially included all such variables, and were reduced via step-wise removal of the least significant, until only significant variables remained (at the 0.05 level). All variables were then individually re-added to the model and were included if they were found to be significant.

Results

Trapping of B. parvus

Eighty-four trapping sites were clustered into seventeen geographic units based on average distance between boulderfields using eastings and northings in JMP 3 (SAS Institute). These were increased to 20 clusters on the basis of topography by separating Dicky Cooper from Whites River, Muellers from Townsend, Etheridge from Kosciuszko, and including Byatts Camp in the Townsend cluster rather than with Wilkinsons Valley (Figure 1). A compilation of trapping results for these clusters are presented in Table 2.

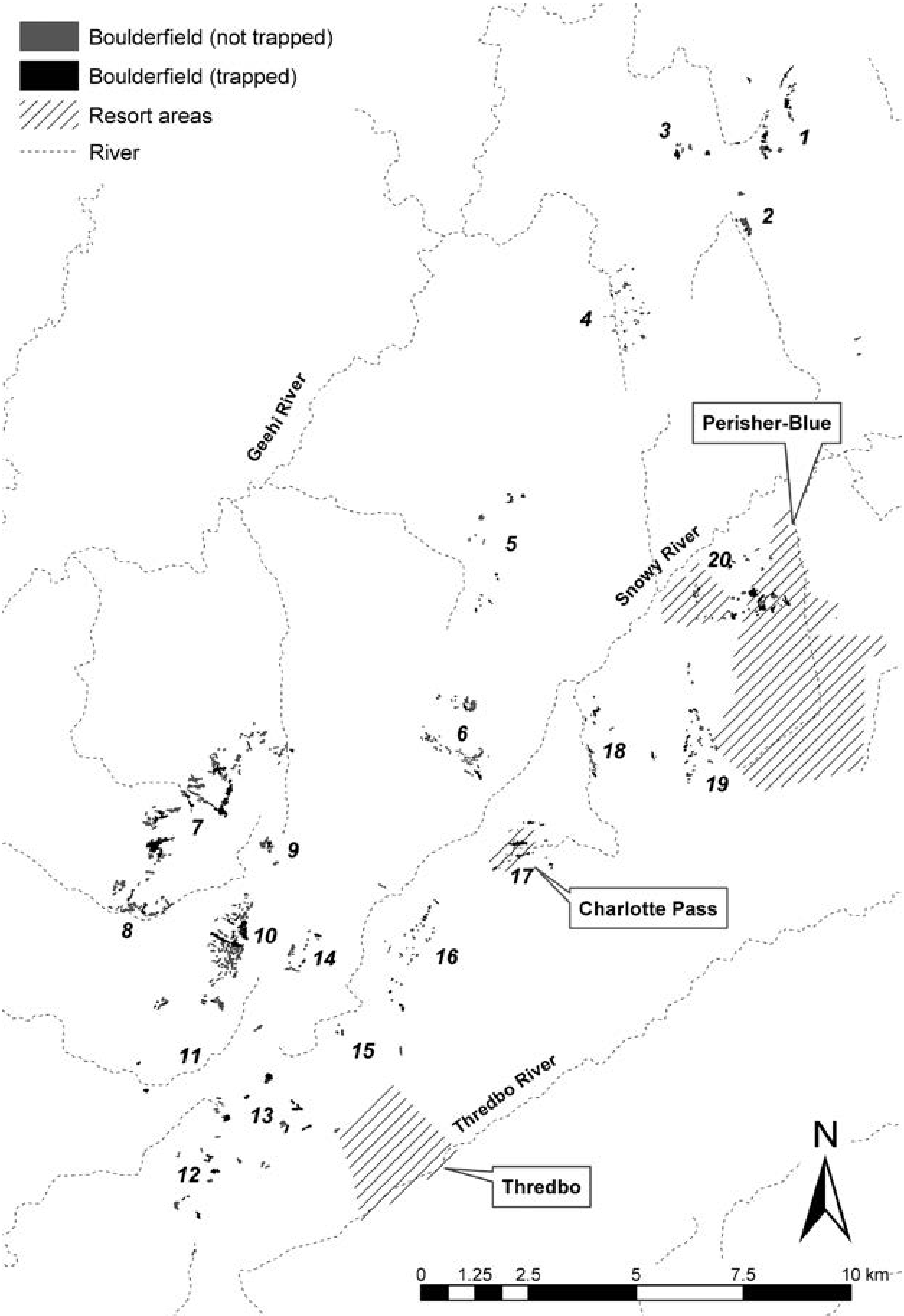

Figure 1. The distribution of boulderfields in the Kosciuszko Plateau region of Kosciuszko National Park. Numbers refer to boulderfield clusters described in Table 2.

Table 2. Trapping results for Mountain Pygmy-possum and other small mammals* in Kosciuszko National Park.

		Number of *B. parvus* trapped				Number of hectares			Population estimates+			Density (no/ha trapped)			
Cluster #	Boulderfield cluster name	Females	Males	F+M	% of Total	Total	trapped	not trapped	DensityBp	Total Bp	% of Total	Mf	Rf	Asw	Aa
1	Gungartan-Gungartan Pass	7	4	11	3.3	10.6	6.1	4.5	1.8	19	2.8	0.5	2.0	0.3	0.0
2	Whites River	2	1	3	0.9	5.1	1.0	4.1	3.0	15	2.2	0.0	0.0	0.0	0.0
3	Dicky Cooper	0	0	0	0.0	3.5	2.3	1.2	0.0	0	0.0	0.0	0.0	0.0	0.0
4	Windy Creek	3	0	3	0.9	3.9	0.7	3.3	4.5	18	2.6	0.0	1.5	0.0	0.0
5	Anton-Anderson	0	0	0	0.0	3.3	2.0	1.2	0.0	0	0.0	0.0	0.5	0.0	0.0
6	Blue Lake-Headley Tarn	1	1	2	0.6	9.3	2.1	7.1	0.9	9	1.3	0.0	1.9	0.5	0.0
7	Townsend-Byatts Camp	35	6	41	12.1	44.8	21.7	23.0	1.9	84	12.5	0.1	1.0	0.1	0.0
8	Wilkinsons Valley	0	0	0	0.0	11.0	2.0	9.0	0.0	0	0.0	0.0	0.5	0.0	0.0
9	Muellers Peak	7	7	14	4.1	3.8	0.9	2.9	15.1	58	8.5	0.0	0.0	0.0	0.0
10	Mt Kosciuszko	27	9	36	10.7	25.9	10.0	15.9	3.6	93	13.8	0.0	3.8	0.0	0.0
11	Cootapatamba-Swampy Plain	6	2	8	2.4	6.2	2.2	4.0	3.6	22	3.3	0.4	5.8	0.9	0.0
12	Central-South Ramshead	3	1	4	1.2	9.4	4.4	5.0	0.9	9	1.3	0.0	3.2	0.7	0.2
13	Thredbo-North Ramshead	1	1	2	0.6	7.9	5.6	2.3	0.4	3	0.4	0.5	2.5	0.4	0.0
14	Etheridge	5	2	7	2.1	3.5	1.0	2.5	7.1	25	3.7	2.0	5.1	1.0	0.0
15	Snowy-Merrits	0	0	0	0.0	2.4	1.8	0.6	0.0	0	0.0	2.8	0.0	0.0	0.0
16	Summit Road	11	10	21	6.2	3.6	1.3	2.3	16.2	59	8.7	0.8	13.1	0.8	0.0
17	Charlotte Pass	31	31	62	18.3	4.8	4.3	0.5	14.3	69	10.2	0.7	10.9	1.4	0.2
18	Spencers Creek	12	11	23	6.8	3.2	2.1	1.2	11.2	36	5.3	0.0	14.6	0.0	0.0
19	Paralyser	21	10	31	9.2	7.1	3.4	3.6	9.0	64	9.4	1.2	7.0	0.9	0.9
20	Blue Cow-Guthega	46	24	70	20.7	15.6	11.7	4.0	6.0	94	13.9	0.3	3.6	0.7	0.5
	TOTAL	218	120	338		184.8	86.7	98.2		677					
% in ski resorts (cluster 17, 20)					39.1						24.1				
average sex ratio Bp				1M:1.82F											

* Bp - *Burramys parvus*, Mf - *Mastacomys fuscus*, Rf - *Rattus fuscipes*, Asw - *Antechinus swainsonii*, Aa - *Antechinus agilis*

\+ this is highly likely to be an over-estimate on some sites - see population estimation section

A total of 338 *B. parvus* were captured at 50 sites. Low numbers of *B. parvus* (five or fewer females) were trapped in half of the habitat clusters. The highest numbers were obtained at Charlotte Pass, Blue Cow–Guthega, Townsend-Byatts and Kosciuszko (Table 2). Numbers of *B. parvus* trapped fluctuate from year to year, but the population estimates on the four monitoring sites in 1997, when a large proportion of the sites were trapped, were not significantly less than the 15 year averages (Broome 2001a, unpubl. data). Numbers trapped on the monitoring sites during the years randomly selected to include in this study did not differ from the means by more than 2 individuals, with the exception of number of females at Charlotte Pass, which was 5 above average (this would make only a 1% difference to the percentage totals in Table 2).

Other small mammal species loosely associated with *B. parvus* in the boulderfields included *M. fuscus* (0.25) and *A. swainsonii* (0.30) which were trapped in low numbers at approximately half of the clusters. Agile antechinus *Antechinus agilis* was rarely recorded, while *R. fuscipes* (0.51) occurred in 80% of the clusters (Table 2). Numbers of these species on the four monitoring sites were also as high or higher than the 10 year averages in 1997, except for low numbers of *R. fuscipes* on the Paralyser site.

Trapping results from sites surveyed by Broome (unpubl data) in previous years are presented in Appendix 1, results from Caughley's surveys in Appendix 2 and details of the trapping results from this study in Appendix 3.

Abundance and density of *B. parvus* were only moderately correlated (0.59), making modelling of each necessary. No single variable was a good predictor of *B. parvus* presence, abundance or density. Complexity, which was not included in modelling analysis (see methods), was the only variable obviously correlated with *B. parvus* presence (0.56), abundance (0.48) and density (0.44). However, although not directly modelled, significant factors in the final regression models (Table 3) reflected the importance of characteristics that constituted the "complexity" variable. The importance of boulder structure was indicated by PC1 of boulder layers and PC 2 of boulder count being significant in all models. PC1 of boulder layers distinguished boulderfields that had more than two layers (negative values, associated with possums) from those that did not (Table 4), while PC2 of boulder count distinguished boulderfields dominated by boulders greater than 1m in diameter (positive values), from those that had a more even distribution of boulder sizes (negative values, associated with *B. parvus*). PC1 of boulder count was also significant in the presence model, indicating that presence of boulders of all sizes was important to the presence of possums. PC2 of boulder count was significant in the abundance model, which is more difficult to explain, as negative values (associated with possums) identified sites with more three-layered plots, but also more plots with no layers, possibly indicating a diversity of habitats within a site. Vegetation characteristics contributed to all models. There was a significant positive correlation between floristic diversity and possum abundance and presence, and a significant positive correlation between the degree of vegetation cover and density and presence of *B. parvus*. The percentage snow cover was significant in the abundance model, with sites with high numbers of possums tending to have high snow cover. None of these models was a particularly good fit to the data (R^2= 0.2849 presence, 0.3253 density and 0.3274 abundance: Figures 2 and 3). However, deeper boulderfields with a variety of boulder sizes and reasonable vegetation cover are obviously implicated as preferred habitat.

Table 3. Significant variables from regression models.

Variable	Presence/ absence	Abundance	Density
% Snow cover	n.s.	(+) 0.0021	n.s.
Floristic diversity	(+) 0.0318	(+) 0.0021	n.s.
Boulder count PC2	(-) 0.0402	(-) 0.0013	(-) <0.0001
Layers PC1	(-) 0.0024	(-) 0.0031	(-) <0.0001
Layers PC2	n.s.	(-) 0.0131	n.s.
Boulder count PC1	(+) 0.0103	n.s.	n.s.
Veg. cover PC1	(+) 0.0146	n.s.	(+) 0.0062

Table 4. Weightings for significant principal components.

Category	PC1	PC2
Eigen value	2.73	1.32
Percent	54.59	26.45
Cum percent	54.59	81.03
BC <20cm	0.55	-0.12
BC 20-50cm	0.55	-0.25
BC 50-100cm	0.54	-0.06
BC 1-2m	0.32	0.58
BC >2m	0.06	0.76
Eigen value	1.95	1.32
Percent	48.79	33.2
Cum percent	48.79	81.99
PL 0	0.48	-0.49
PL 1	0.54	0.41
PL 2	-0.39	0.63
PL 3+	-0.57	-0.45
Eigen value	1.92	
Percent	63.84	
Cum percent	63.84	
PV <20%	-0.71	
PV 20-80%	0.41	
PV >80%	0.57	

BC= Boulder class, PL Proportion of layers, PV Proportion veg class.

The expected effect of altitude on other variables was readily apparent, and helps in interpreting some of the noise associated with the modelling results. Floristic diversity was a significant factor in presence and abundance models. However, there was a clear negative association between altitude and floristic diversity (-0.75), and altitude and vegetation cover (-0.60), yet some high altitude sites

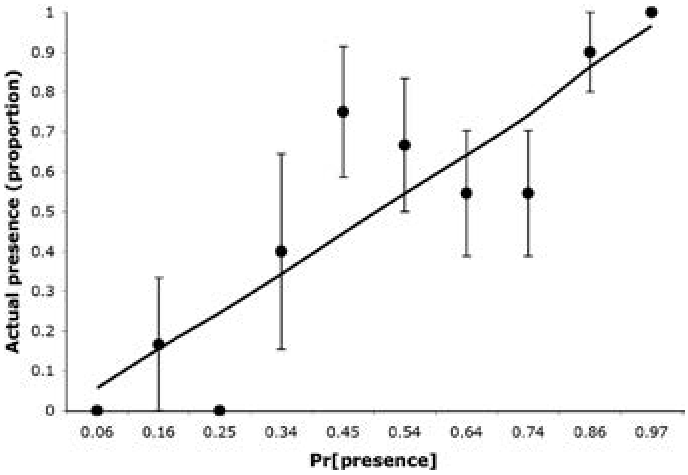

Figure 2. Model fit for possum presence. Line represents whole model prediction of possum presence. Circles are the actual proportion of occurrence of possums at sites within a particular prediction class (reduced to 10 categories for ease of presentation. Error bars are +/-1 standard error.

(Kosciuszko and Townsend in particular) have high numbers of possums despite their low vegetation diversity and cover. This is probably explained by the fact that plants are important food sources, but at higher altitudes where plants were less abundant, another important food source, Bogong Moths *Agrotis infusa*, were more abundant than at low altitudes (correlation 0.53), and could offset lack of other foods (Smith and Broome 1992, Gibson 2007).

Estimation of population size

Calculating an unadjusted population estimate (N) by multiplying the average density estimates by the total area of habitat within each boulderfield cluster (Table 2) will almost certainly produce a high estimate of the population size in most clusters. This is because the boulderfield areas not trapped were of lower complexity, i.e. had few layers, low vegetation cover or were shallower than those selected for trapping. This was particularly evident for areas such as Whites River, Muellers Peak, Kosciuszko, Summit Road and Paralyser, where there was a relatively large amount of untrapped, low quality boulderfield. Adding 11% to the resultant cumulative estimate of 677 in Table 2 (to adjust for the difference between numbers caught (N) and the expected population estimate (N-hat) and adding a confidence interval of 15%, see methods) produces a very optimistic estimate of 750±112 adult *B. parvus* in Kosciuszko National Park. An alternative method is to apply an average density estimate to the untrapped portion of the habitat and add this to the total for the trapped sites. Use of the unweighted average density over all trapped boulderfields (338 animals / 86.7 ha = 3.90/ha) results in a high estimate of (338+383) + 11% = 800±120. However, the median density (2.18/ha) is likely to produce a more realistic estimate because less weight is given to the highest densities. This produces a total of (338+214) + 11% = 613±92 adult *B. parvus* (395 females and 218 males) in southern Kosciuszko National Park between 1996-2001.

Very conservatively our results show that 24% of the southern Kosciuszko population was within the boundaries of the Charlotte Pass and Perisher-Blue ski resorts, but this may have been as high as 39% (Table 2).

Prediction of habitat distribution and modelling of habitat variables

The modelling of potentially suitable climates based on the known colonies of *B. parvus* surveyed between 1996-2001 in southern Kosciuszko (South Ramshead to Gungartan Pass) predicted areas above 1600 metres in a limited region of southern Kosciuszko that included areas of the Cascade ranges and around Mt Jagungal, where possums have not been recorded (Figure 4). Boulderfields on Mt

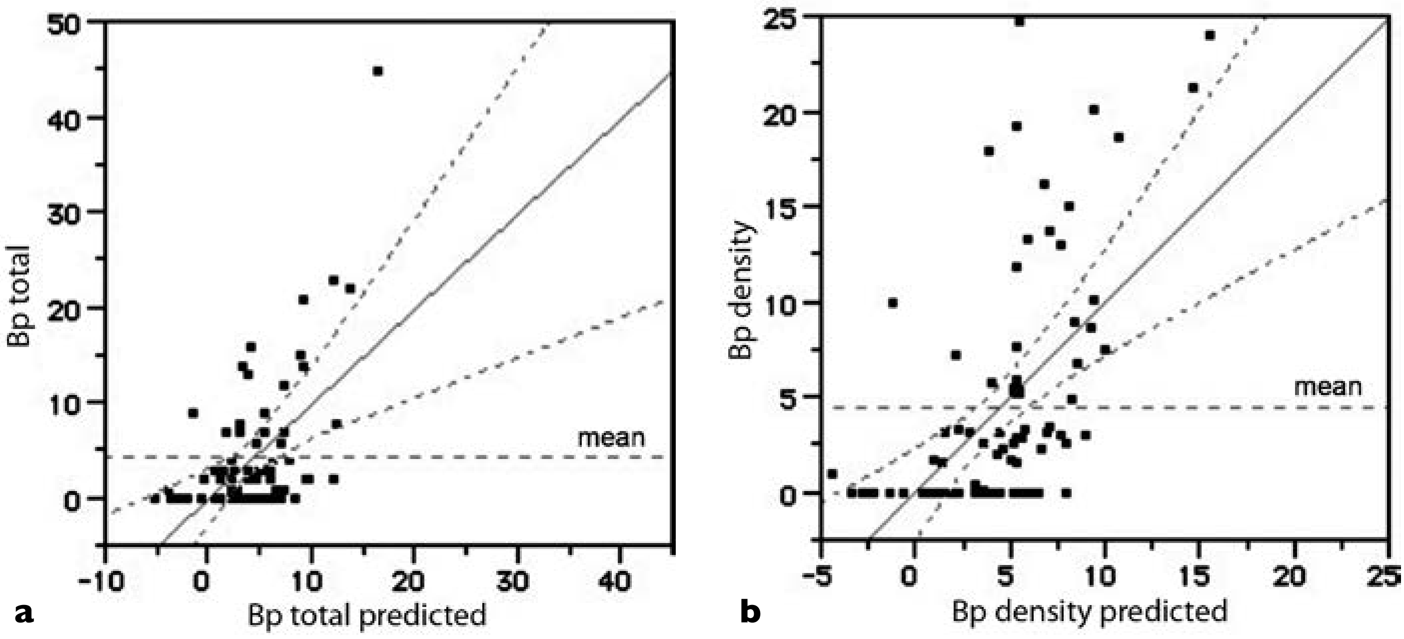

Figure 3. Model fit for possum abundance (a) (individuals/site), (b) possum density (individuals/ha). Solid line is the predicted occurrence with 95% confidence limits shown as dotted line.

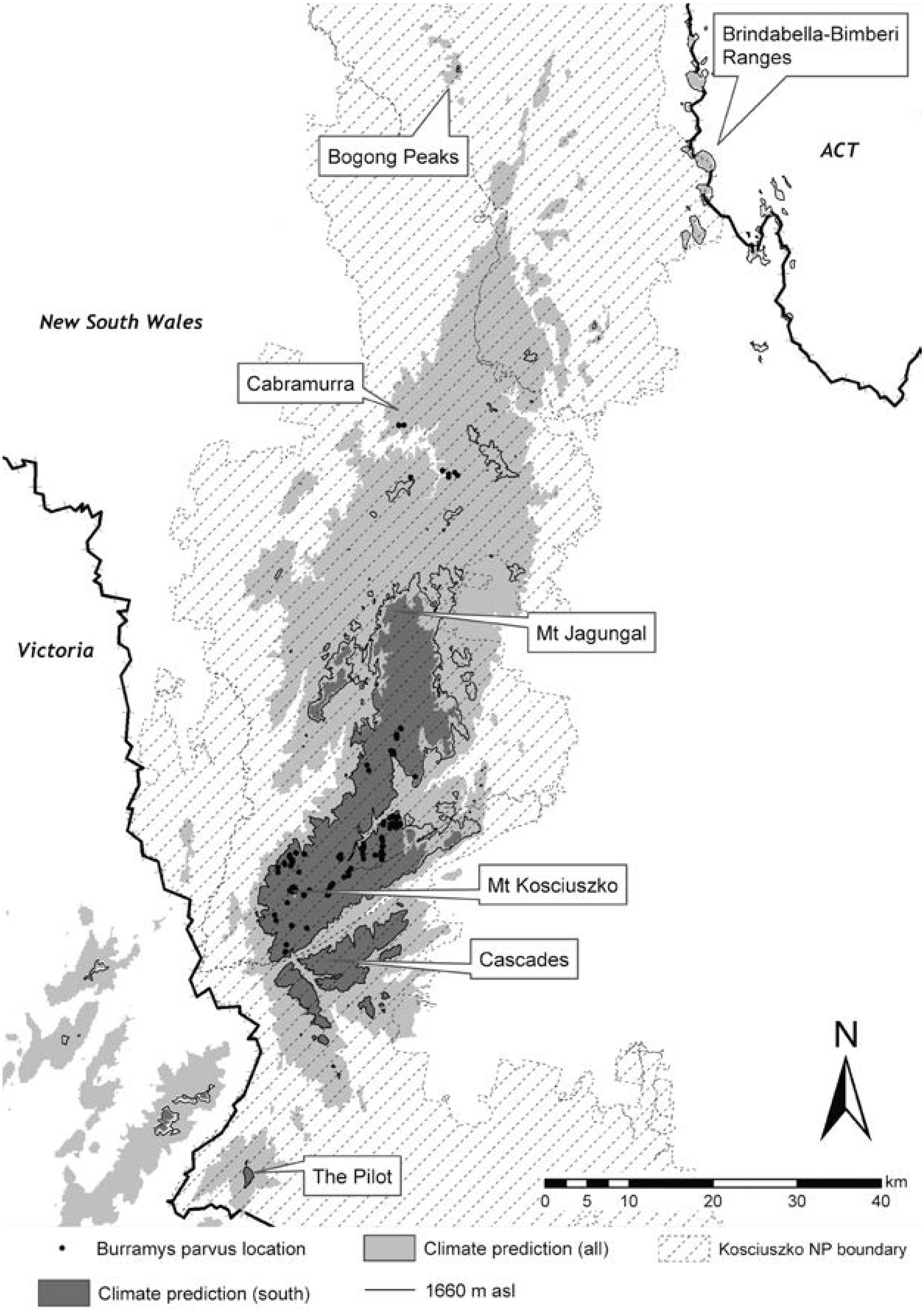

Figure 4. Climatic predictions based on known populations of *Burramys parvus* in NSW. The "south" prediction is based on populations studied in the survey component of this study, the "all" prediction includes the recently discovered northern population.

Jagungal have been trapped twice (in 1987 and 2009) with no success, while no well-defined boulderfields have been noted on the Cascades. The total area predicted as suitable climate was 44,416 ha. Within that area 185 ha of boulderfield was mapped, with 75 ha total area known to contain possums.

In 2010-11 three new colonies of *B. parvus* were discovered at elevations below 1660 m near Cabramurra in the northern section of Kosciuszko National Park (Schulz *et al.* 2012 a, Broome *et al.* 2012, Broome, Bates and Shi unpubl. data). Inclusion of successfully trapped boulderfields near Cabramurra dramatically increased the potential distribution of *B. parvus* in NSW, as the new potential climatic envelope (207,864 ha) includes a number of previously unsurveyed boulderfields as far north as the Bogong Peaks and Brindabella Ranges (Figure 4). Boulderfields identified from aerial photographs and satellite imagery within this broader region will be targeted for future surveys, and may contain populations of possums not considered in the population estimate presented here. However, the density of boulderfields within the wider potential distributions is markedly lower and more patchy than in the southern distribution.

Discussion

We estimated the total number of adult *B. parvus* in Kosciuszko National Park during these surveys (1996-2001) to be around 613 ± 92 but optimistically numbers may range up to 860. Despite the fact that Caughley's (1986) estimate was based on a lower mean density of adult *B. parvus* than we found, our estimate is closer to the 500 adults estimated by Caughley (1986) than to the 1312 revised estimate (Broome and Mansergh 1989). This is because the heterogeneity of boulderfield habitats is far greater than previously recognised, and the total area of *B. parvus* habitat, particularly high quality habitat, identified by this study was significantly less than that on which Caughley based her estimate. It is evident from the current survey that the densities of *B. parvus* in the four monitoring sites were higher than the average or median densities, hence the inflated estimate of Broome and Mansergh (1989). Although our approach was to map and survey boulderfields and not include surrounding areas of heath with scattered boulders as Caughley did, it is evident that the extent of heath and boulderfield habitat as mapped by Caughley (1986) was overestimated in some areas. Mapping largely from high level (1:24,000) aerial photographs, Caughley (1986) included areas that had only surface rock and large areas of grassland, particularly on the western scarp of Abbott Ridge including Mt Townsend, where half the habitat (4.35 km^2) was thought to occur. This led to the assumption that over half of the population occurred in that area (rather than 12% as indicated by this study), well away from any development activity. Further, it was assumed that the population of *B. parvus* in the proposed Blue Cow ski resort represented 1% of the numbers in Kosciuszko National Park (Caughley 1983, 1984, National Parks and Wildlife Service 1985) rather than 14-20% indicated by this study.

The largest populations of *B. parvus* occurred in the two ski resort lease areas, with the next highest numbers on the peak of Mt Townsend and the western fall of Abbott Ridge (cluster 7 Townsend-Byatts Camp) and Mt Kosciuszko. However, except for the very peaks of these mountains, densities were generally quite low in the latter two areas, reflecting extensive areas of relatively low quality habitat. Many of the boulderfields on the western slopes of Abbott Ridge e.g., at Byatts Camp and those in Wilkinsons Valley were characterised by very large boulders and only one male possum was trapped at those sites. Vegetation cover was low and boulder depth quite shallow in the extensive boulderfields on the west side of Mt Kosciuszko. The habitat analysis indicated that preferred habitats were characterised by deeper boulderfields with a variety of boulder sizes and reasonable vegetation cover. Floristic diversity was important in explaining the presence and abundance of *B. parvus* but was not significantly correlated with density. This was because some of the highest densities occurred in boulderfields on the mountain peaks, including boulderfields on the summits of Mt Townsend, Muellers Peak, Kosciuszko and Etheridge Ridge, where there was low vegetation diversity or cover but good boulderfield structure and high numbers of Bogong Moths. Bogong Moths form a large part of the diet of *B. parvus* in summer and attain highest densities in boulderfields at high elevations (Mansergh *et al.* 1990, Smith and Broome 1992, Broome 2001b, Green 2010).

Previous research has shown that high quality *B. parvus* habitat is comprised of deep boulderfields at high elevations with associated shrubby heathland characterised by *Podocarpus lawrenceii* and *Leucopogon* spp., and high numbers of Bogong Moths (Mansergh and Scotts 1990, Mansergh and Broome 1994, Broome 2001b). At Mt Blue Cow the population uses a mosaic of boulderfield patches and shrubby heathland, with some males travelling and returning on a nightly basis up to 1.5 km between boulderfield patches and females up to 1 km from low to high elevations to access Bogong Moths (Broome 2001b). Shrubs provide the principal autumn dietary source of seeds and berries (Mansergh *et al.* 1990, Smith and Broome 1992, Gibson 2007) and also provide habitat for caterpillars, beetles, spiders and millipedes, arthropod dietary items of secondary importance for *B. parvus*. Unvegetated boulderfields (screes) were found by Green (1988) to have low numbers of invertebrates in pitfall and litter samples.

The Kosciuszko Peak boulderfield was surveyed a number of times between 1990-1998 (Appendix 1). In 1990, 77 individuals were trapped during the combined February and March surveys (15 adult females, 12 adult males and 50 juveniles). In April 1992, the heaviest individual ever trapped, an 82 gram female fattened for winter hibernation (Broome and Geiser 1995) was trapped at this site. The site is unvegetated, but during these surveys high numbers of Bogong Moths were aestivating at the site. However, only 2 females were trapped in December 1993, a near or above average year for *B. parvus* populations on the monitored sites (Broome 2001a) but few Bogong Moths were present. It is likely that the populations of *B. parvus* in this cluster and other sites such as Townsend and

Muellers are highly dependent on the migratory Bogong Moths and these populations may vary in size according to conditions that affect Bogong Moth populations in their lowland breeding grounds. Possums may move between the rocky peaks and the shrubby slopes below, as was found at Mt Blue Cow (Broome 2001b), however at Kosciuszko and Muellers nearby shrubby heathland is sparse. Habitat areas with good vegetation cover and diversity that support relatively large populations include those at Summit Road, Charlotte Pass, Spencers Creek, Paralyser and Blue Cow. Possums in these areas would have a greater potential to diversify their diets so population stability is likely to be greater at these sites. These shrubby sites were also where *R. fuscipes* occurred in high densities.

High numbers of *B. parvus* were not detected by Caughley (Appendix 2) on many of what we have found to be key sites because either the principal, high quality parts of the site were not trapped (generally the high altitude rocky peaks), or trapping was conducted after many individuals, particularly adults, would have commenced hibernation. It was not known at the time of Caughley's surveys that adult *B. parvus* hibernate and become untrappable from late February and juveniles from March or April (Broome and Geiser 1995, Walter 1996, Körtner and Geiser 1998, Broome 2001b). Mt Stillwell, Muellers and the Paralyser, for example were trapped by Caughley in late April and the main Charlotte Pass boulderfield in May. Unaware of the overwinter hibernation strategy of *B. parvus*, Caughley (1981) reported that the reason no *B. parvus* were trapped at Muellers in late April was not obvious. While Summit Road was trapped by Caughley in March, only juveniles were captured and the subsites trapped on Mts Blue Cow and Townsend included some of the mid-elevation sites, but not the peaks where highest densities occur (Broome 2001b, Appendix 3).

Our 1996-2001 surveys resulted in a small extension of the known range along Kerries Ridge at the northern end of the then known distribution area (noted but not mapped by Caughley due to a limit in aerial photo coverage). However, BIOCLIM modelled a much larger area north of the Main Range and Kerries Ridge as suitable climate for *B. parvus*. Broome (unpubl. data) trapped Mt Jagungal in 1987 and found no evidence of *B. parvus* or habitat suitable for the species on the mountain peak. Boulderfields on the western slope of Mt Jagungal were trapped in 2009, again with no success. The area was extensively burnt in the 2003 wild fires and all mature *P. lawrencei* perished. Although substantial boulderfields are not evident from small-scale aerial photos, ridges in the Brassy, Dargals and Grey Mare Ranges would be worthy of further investigation, as would the Chimneys Ridge south of the Thredbo River (Figure 2). Caughley surveyed around Mt Selwyn in October 1980 with negative results. Evidence of *B. parvus* presence (cross-sectioned *P. lawrencei* seeds, Mansergh and Broome 1994) was detected at some small patches of boulderfield that were not trapped in this survey viz. Farm Creek between cluster 19 and 20 (Figure 1) and on the slopes of Disappointment Ridge, (south of cluster 2 and north of cluster 20, Figure 1). A female was trapped at one of the Disappointment Ridge sites in February 1999 (Glen Sanecki pers. com.) and two males were trapped by K. Green in February 2003 and April 2004 at the northern end of Kerries Ridge, approximately 3 km north of cluster 1. However, it was not expected that substantial additional areas of habitat would be found, because of the restriction of known breeding populations in the southern Kosciuszko region to elevations above ca. 1600m elevation, variant slightly on latitude and aspect (Caughley 1986, Broome 2001a,b, this study), although captures of individual animals had been made as low as 1400 m. As our results have illustrated, any new areas can be rapidly assessed by experienced observers using the complexity rating.

Recent discoveries of an additional three *B. parvus* colonies between Mt Jagungal and Cabramurra (Snow Ridge, Rough Creek, Boltons Hill – Happy Jacks Valley) in the northern Kosciuszko region resulted in the capture of 29 adults (15 females, 14 males) and 47 juveniles (22 females and 25 males) during November 2010 – January 2011. Surveys at the same sites during October – November 2011 and 2012 resulted in the capture of 160 adults (124 females and 36 males) (Schulz *et al.* 2012a, b, L. Broome, H. Bates, H. Shi unpubl. data). Potential boulderfield habitat between Mt Jagungal and the Brindabella Ranges has been digitised from aerial photo coverage. Surveys were conducted in two of these identified sites during October 2011 (Byron and Kiandra), at Farm Ridge and Toolong Range in December 2012 and Bogong Peaks in February 2013 with no captures of *B. parvus*. Trapping in January 2012 on a spoil dump deposited by the Snowy Hydro-electric Scheme in the 1950s near Guthega (Guthega Adit Camp) on the northern banks of the Snowy River close to cluster 20 (Figure 1) resulted in the capture of an additional 5 adult females and 4 adult males (Schulz *et al.* 2012b). At this point, predictions using densities from the successful sites and mapping of potential habitat suggests that locating more than an additional 250 adult females and 80 adult males is unlikely (L. Broome, H. Bates, H. Shi unpubl. data).

Provision of a point-in-time estimate of total population size is necessarily approximate because changes occur due to the influence of climatic trends, population sizes of colonies can fluctuate independently due to local conditions (e.g., Broome 2001a) and uncertainty occurs in the accuracy of estimates. There has also been the additional, unexpected discovery of new colonies. However, the total population on the Kosciuszko plateau (optimistically about 395 adult females and 218 males south of Mt Jagungal estimated from this study in 1996-2001, with perhaps an additional 250 adult females and 80 males in newly discovered colonies north of Mt Jagungal) is small. Most local populations of breeding females are much smaller than 20, which has been cited as the minimum number below which demographic stochasticity is a real threat (Soule 1987, Hanski 1991). McCarthy and Broome (2000) suggested that because of the strength of density dependence, populations of *B. parvus* greater than 15 females are relatively safe from extinction from stochastic processes under (then) current conditions. However, only a third to a half of the clusters meet this criterion, unless there is substantial movement between them. Genetic analysis of hairs from each capture will be carried out to determine the degree of isolation of clusters.

In 1994 the total population size across the species range was estimated at about 2600 adults, 1300 in Victoria and 1300 (an overestimate as indicated by this study) in NSW (Broome and Mansergh 1989, Mansergh and Broome 1994). An additional population was discovered at Mt Buller in 1995, increasing the Victorian estimate by 300 adults (Heinze and Williams 1998). Heinze *et al.* (2004) presented a revised estimate of 2056 adults (1570 females, 486 males) in which the population at Kosciuszko was suggested to be around 250 adult females. This was due to declines in the southern Kosciuszko colonies that began in the late 1990's. By 2009, the numbers in the four colonies in the southern Kosciuszko distribution that exceeded 25 females (clusters 7, 10, 17, 20 in Table 2) had declined by between 36-77%, with an overall decline of 43% and a population estimated at around 355 adults (225 females and 130 males, Broome *et al*. 2012). Trapping on the southern Kosciuszko long-term monitoring sites in November 2011, 2012 and 2013 indicated a recovery at Charlotte Pass and Kosciuszko and a partial recovery at Mt Blue Cow (currently 50% of 1986-99 numbers). Mt Townsend was not trapped, but given unprecedented high numbers on the other monitoring sites (Summit Road and Paralyser) and at Gungartan, Gungartan Pass and Whites River, it is probable this colony has also recovered. These recoveries follow a return to four years of high rainfall. It is therefore likely that the current population on the southern Kosciuszko plateau is similar to that estimated in this study. In round figures, with the addition of predicted numbers from colonies north of Mt Jagungal, the adult population on the Kosciuszko plateau in 2011-2013 is likely to be in the order of 950 adults (*ca*. 650 females and 300 males).

Acknowledgments

This research was funded by the Foundation for National Parks and Wildlife of New South Wales with sponsorship from David Archer to whom we are extremely grateful and the New South Wales Office of Environment and Heritage. Snowy Hydro Ltd. kindly provided helicopter time. We thank the many volunteers who assisted with the trapping and habitat surveys and the two anonymous reviewers who reviewed this manuscript.

References

Anon, 1966a. New animal found: link with past survives in Victoria. *National Sporting Shooter's Journal* (October) **5:** 3.

Anon 1966b. A relict marsupial. *Nature* **212**:225.

Broom, R. 1896. On a small fossil marsupial with large grooved premolars. *Proceedings of the Linnean Society of NSW* **10**: 563.

Broome, L.S. 1992. Ecology and management of the Mountain Pygmy-possum, *Burramys parvus* Broom, in Kosciusko National Park. *Consultants report to the NSW National Parks and Wildlife Service*. Sydney, NSW.

Broome, L.S. 2001a. Intersite differences in population demography of Mountain Pygmy-possums *Burramys parvus* Broom (1987-1998): Implications for metapopulation conservation in Kosciuszko National Park. *Biological Conservation* **102**: 309-323.

Broome, L.S. 2001b. Seasonal activity, home range and habitat use of the mountain pygmy-possum *Burramys parvus* (Marsupialia: Burramyidae) at Mt Blue Cow, Kosciuszko National Park. *Austral Ecology* **26**: 275–292.

Broome, L.S. and Geiser, F. 1995. Hibernation in free-living Mountain Pygmy-possums, Burramys parvus (Marsupialia: Burramyidae). *Australian Journal of Zoology* **43**: 373-379.

Broome, L. and Mansergh, I. 1989. The Mountain Pygmy-possum (*Burramys parvus*) Broom : an alpine endemic. Pp 241-265 in *The scientific significance of the Australian Alps,* edited by R. Good. Australian Alps Liaison Committee / Australian Academy of Science, Canberra.

Broome, L.S., Dawson M., Ford F., Green K., Little, D. and McElhinney, N. 2005. Re-assessment of Mountain Pygmy-possum *Burramys parvus* population size and distribution of habitat in Kosciuszko National Park. Unpublished report, Biodiversity Conservation Section, Department of Environment and Conservation,, Queanbeyan, NSW.

Broome, L. Archer, M., Bates, H., Shi, H., Geiser, F., McAllan, B., Heinze, D., Hand, S., Evans, T., and Jackson, S. 2012. A brief review of the life history of, and threats to, *Burramys parvus* with a pre-history-based proposal for ensuring that it has a future. Pp 114-126, in *Wildlife and Climate Change: towards robust conservation strategies for Australian fauna* edited by D. Lunney. Royal Zoological Society of NSW, Mosman, NSW.

Calaby, J.H., Dimpel, H. and McTaggart-Cowan, I. 1971. The Mountain Pigmy Possum, *Burramys parvus* Broom (Marsupialia), in the Kosciusko National Park, New South Wales. *CSIRO Division of Wildlife Research Technical Paper*: No. **23,** CSIRO, Canberra.

Caughley, J. 1981. Report on field trip to Lake Albina, Kosciusko National Park 16-20 April 1981. National Parks and Wildlife Service Scientific Services unpublished report, 22-04-81. Sydney, NSW.

Caughley, J. 1983. Annual Report on *Burramys parvus* in Kosciusko National Park 1983. National Parks and Wildlife Service Scientific Services unpublished report, 14-06-83. Sydney, NSW.

Caughley, J. 1984. Additional information on the abundance of *Burramys parvus* in the Blue Cow development area. National Parks and Wildlife Service Scientific Services unpublished report, 17-12-84. Sydney, NSW.

Caughley, J. 1986. Distribution and abundance of the Mountain Pygmy-possum, *Burramys parvus* Broom, in Kosciusko National Park. *Australian Wildlife Research* **13**: 507-517.

Galloway, R. W. 1989. Glacial and Periglacial features of the Australian Alps. Pp. 55-67 in *The scientific significance of the Australian Alps,* edited by R. Good. Australian Alps Liaison Committee / Australian Academy of Science, Canberra.

Gibson, R. 2007. The role of diet in driving population dynamics of the Mountain Pygmy-possum, *Burramys parvus*, in Kosciuszko National Park, NSW. Honours Thesis, Division of Botany and Zoology, Australian National University, Canberra.

Green, K. 1988. A study of *Antechinus swainsonii* and *Antechinus stuartii* and their prey in the Snowy Mountains. Ph.D. thesis, Australian National University

Green, K. 2010. The aestivation sites of Bogong Moths, *Agrotis infusa* (Boisduval) (Lepidoptera: Nocturidae), in the Snowy Mountains and the projected effects of climate change. *Australian Entomologist* **37**: 93-104.

Gullan, P.K. and Norris, K.C. 1984. The habitat of the Mountain Pygmy-possum *Burramys parvus* in Victoria. Pp. 417-421 in *Possums and Gliders*, edited by A.P. Smith and I.D. Hume. Australian Mammal Society, Sydney.

Hanski, I. 1991. Single-species metapopulation dynamics: concepts, models and observations. *Biological Journal of the Linnean Society* **42**: 17-38.

Heinze D. and Williams L. 1998. The discovery of the Mountain Pygmy-possum, *Burramys parvus* on Mount Buller, Victoria. *Victorian Naturalist* **115**: 132-134.

Heinze, D., Broome, L. and Mansergh I. 2004. A review of the ecology and conservation of the mountain pygmy-possum *Burramys parvus.* Pp. 254-267 in: *The Biology of Australian Possums and Gliders* edited by R. L. Goldingay and S. M. Jackson. Surrey Beatty & Sons, Chipping Norton.

Körtner, G. and Geiser, F. 1998. Ecology of natural hibernation in the marsupial mountain pygmy-possum (*Burramys parvus).* *Oecologia* **113**: 170-78.

Lourens, U., Schelling, K. and Walter K. 2002. Snow cover and snow duration determination from satellite imagery for mountain pygmy-possum habitat in Kosciuszko National Park. Report to the New South Wales National Parks and Wildlife Service. Agricultural Reconnaissance Technologies Pty. Ltd.

Mansergh, I.M., Kelly, P. and Scotts, D.J. 1989. Management strategy and guidelines for the conservation of the Mountain Pygmy-possum (*Burramys parvus*) in Victoria. *Arthur Rylah Institute for Environmental Research Technical. Report No.* **66**.

Mansergh, I., Baxter, B., Scotts, D., Brady, T. and Jolley, D. 1990. Diet of *Burramys parvus* (Marsupialia: Burramyidae) and other small mammals in the alpine environment at Mt Higginbotham, Victoria. *Australian Mammalogy* **13**: 167-77.

Mansergh, I. and Scotts, D. 1990. Aspects of the life history and breeding biology of the Mountain Pygmy-possum *(Burramys parvus*) (Marsupialia: Burramyidae) in alpine Victoria. *Australian Mammalogy* **13**: 179-91.

Mansergh, I. M., and Broome, L. S. 1994. The Mountain Pygmy-possum of the Australian Alps. University of New South Wales Press, Sydney.

McCarthy, M. A. and Broome, L. S. 2000. A method for validating stochastic models of population viability: a case study of the mountain pygmy-possum (*Burramys parvus*). *Journal of Animal Ecology* **69***: 599-607.*

National Parks and Wildlife Service. 1985. Proposed Blue Cow Ski Resort Kosciusko National Park Environmental Impact Statement. National Parks and Wildlife Service, March 1985. Queanbeyan, NSW.

Nix, H. A. 1986. A biogeographic analysis of Australian Elapid Snakes. pp. 4-15. *In*. R. Longmore (ed.) *Atlas of Elapid Snakes of Australia*. Australian Flora and Fauna Series Number **7**. Australian Government Publishing Service Canberra.

Rosengren, N. J. and Peterson, J. A. 1989. Heritage values and the geological and geomorphological significance of the Australian alpine zone. Pp 187-204 in *The scientific significance of the Australian Alps,* edited by R. Good. Australian Alps Liaison Committee / Australian Academy of Science, Canberra

Schulz, M., Wilks, G. and Broome, L. 2012a. An uncharacteristic new population of the Mountain Pygmy-possum *Burramys parvus* in New South Wales. *Australian Zoologist* **36**:22-28.

Schulz, M., Wilks, G. and Broome, L. 2012b. Occupancy of spoil dumps by the Mountain Pygmy-possum *Burramys parvus* in Kosciuszko National Park. *Ecological Management and Restoration* **13**: 290-296.

Smith, A., and Broome, L.S. 1992. The effects of environment and sex on the diet of the Mountain Pygmy-possum and its implications for the species conservation and management in south-east Australia. *Australian Wildlife Research* **19**: 755-68.

Soule, M. E., ed. 1987. *Viable populations for conservation.* Cambridge University Press, New York.

Walter, A-M. J. 1996. The Ecology of Hibernating Mountain Pygmy-possum *Burramys parvus* in Kosciusko National Park. Honours thesis, University of Canberra.

White, G.C., Burnham, K.P., Otis, D.L. and Anderson, D.R. 1978. User's Manual for Program CAPTURE. Utah State University Press, Logan, Utah, USA.

White, G.C., Anderson, D.R., Burnham, K.P. and Otis, D.L., 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, Los Alamos, New Mexico, USA.

APPENDIX I

Appendix 1. Numbers of individuals trapped at other times between 1988-2001. Bp-*Burramys parvus* =total individuals, other species# = maximum number trapped in any night.

Site	Dates	Traps	Nights	Trap nights	Bp F Ad/S	Bp M Ad/S	Bp F J	Bp M J	Mf	Rf ad/sad	Rf J	Asw ad	Asw J	Aa ad,j
Whites River	4-6/3/89	95	3	285	1	1	5	1	0	3	1	1	15	1,5
Headley Tarn A1	25-26/3/89	100	3	300	1	1	8	0	0	15	8	0	2	0
Headley Tarn A1	20-22/2/90	100	3	300	3	1	8	3	0	11	5	2	0	0
Etheridge Ridge A1	23-24/3/89	50	2	100	1	1	2	1	0	5	1	2	0	0
Mt Guthrie	21-22/12/88	20	2	40	2	3	0	0	0	1	0	0	0	0
Mt Guthrie	24-25/3/89	50	2	100	1	0	1	3	0	14	9	0	4	0
CPass -turnoff	23-24/3/89	25	2	50	0	0	3	0	1	2	2	1	2	0
CPass Sth-BoysA	20-22/12/88	45	3	135	0	5	0	0	0	7	11	0	0	0
CPass Sth-BoysA	23-24/3/89	45	2	90	0	5	2	1	1	3	8	1	17	0,1
CPass Sth-BoysA	10-11/12/95	25	2	50	2	3	0	0	0	7	0	1	0	0
*Mt Kosciuszko-Peak	21-23/2/90	50	3	150	9	2	11	5	1	4	0	1	2	0
*Mt Kosciuszko-Peak	20-21/3/90	75	2	150	9	10	20	19	1	1	0	0	5	0
Mt Kosciuszko-Peak	3/04/1992	75	1	75	5	3	2	5	0	0	0	1	0	0
Mt Kosciuszko-Peak	6-7/12/93	50	2	75	2	7	0	0	0	2	0	1	0	0
Mt Kosciuszko-Peak	10-12/3/98	50	3	75	7	8	0	2	1	1	3	2	1	0
* ***total individuals Feb and March 1990***		**125**	**5**	**300**	**15**	**12**	**27**	**23**						

#Mf - *Mastacomys fuscus*, Rf - *Rattus fuscipes*, Asw - *Antechinus swainsonii*, Aa- *Antechinus agilis*

APPENDIX 2

Appendix 2. Numbers of small mammals* trapped by J. Caughley in Kosciuszko National Park. Bp are individuals, other species are average captures per night

							Total caught					Average No trapped / night		
Site	Dates	Traps	Nights	Trap	Bp F	Bp M	Bp F	Bp M	Bp	Mf	Rf	Asw	Aa	Mm
				nights	Ad/S	Ad/S	J	J	Total		Ad/Sad			
Charlotte Pass (Nth+ Sth)	3-5/5/80	100	1.75	175	0	0	0	0	0	2.3	14.9	13.1	0.0	0.0
E slope Mt Stillwell	11-14/4/80	100	3	300	1	0	2	0	3	7.3	1.0	16.0	0.0	0.0
Mt Selwyn-Kings Cross Ridge	12-16/10/80	100	2	200	0	0	0	0	0	0.0	11.5	0.0	0.0	0.0
Mt Selwyn-Cabramurra airstrip	12-16/10/80	25	2	50	0	0	0	0	0	0.0	3.5	0.0	0.0	0.0
Daners Gap	26-31/10/80	100	2.5	250	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Rennix Gap	26-31/10/80	100	3	300	0	0	0	0	0	0.0	10.0	0.0	0.0	0.0
Perisher Creek	12-14/12/80	100	3	300	0	0	0	0	0	1.0	13.7	0.7	0.0	0.0
Farm Creek	16-18/12/80	100	3	300	0	0	0	0	0	5.7	5.0	0.3	0.0	0.0
Guthrie Range	14-16/1/81	120	3	360	0	0	0	0	0	3.3	10.7	2.0	0.0	0.0
Betts Ck Hill	4-16/1/81	100	3	300	0	0	0	0	0	0.3	2.0	3.3	0.0	0.0
Guthrie Ck	4-16/1/81	50	2	100	0	0	0	0	0	1.5	0.0	1.0	0.0	0.0
Mt Guthrie	4-16/1/81	100	3.25	325	1	0	0	0	1	6.5	0.9	3.7	0.0	0.0
Spencers Ck	4-16/1/81	100	3	300	0	0	0	0	0	1.0	1.7	2.3	0.0	0.0
Stillwell Ridge (Site 1)	1-3/2/81	80	3	240	0	0	0	0	0	3.7	14.0	13.7	0.0	0.0
Summit Rd - above rd (Site 2)	4-6/2/81	80	3	240	3	0	1	0	4	1.3	12.3	17.0	0.0	0.0
Headley Tarn	17-21/2/81	120	3	360	3	1	4	1	9	3.0	11.3	21.0	0.7	0.0

APPENDIX 2

					Total caught					Average No trapped / night				
Site	Dates	Traps	Nights	Trap	Bp F	Bp M	Bp F	Bp M	Bp	Mf	Rf	Asw	Aa	Mm
				nights	Ad/S	Ad/S	J	J	Total		Ad/Sad			
Mt Clarke Circe	25/2-1/3/81	80	3	240	0	0	0	0	0	0.3	24.0	13.0	0.0	0.0
Etheridge Ridge A1	28/3-1/4/81	80	3	240	0	1	0	1	2	7.3	12.3	6.3	0.0	0.0
Muellers NE slope-L. Albina	16-20/4/81	80	3	240	0	0	0	0	0	2.0	4.7	8.3	0.0	0.0
Rolling Grounds	1-5/12/81	100	3	300	0	0	0	0	0	1.7	2.0	0.0	0.0	0.0
Upper Wilkinsons Valley	2-22/1/82	100	3	300	2	3	0	0	5	24.3	15.7	10.0	0.0	0.3
Summit Road (below rd)	5-10/3/82	150	3	450	0	0	5	6	11	3.3	32.3	43.3	0.0	0.0
Whites River	21-25/3/82	100	3	300	0	1	0	3	4	0.0	9.3	12.3	2.0	0.0
Paralyser 1	19-23/4/82	100	3	300	0	0	1	2	3	0.0	13.0	11.0	0.0	0.0
Paralyser 2 (C/D line area)	19-23/4/82	50	3	150	0	0	0	0	0	1.3	9.7	12.3	0.0	0.0
Blue Cow Site A (LBC) 1982	22-26/2/82	100	3	300	1	0	1	0	2	0.0	24.7	20.0	0.0	0.0
Blue Cow Site B (SAL) 1982	8-12/2/82	100	3	300	1	0	4	2	7	3.3	9.0	22.3	0.0	0.0
Blue Cow Site A (LBC) 1983	14/2-30/3/83	200	6	1200	4	0	3	2	9	13.5	20.0	15.7	0.0	0.0
Blue Cow Site B (SAL) 1983	14/2-30/3/83	100	6	600	2	1	2	0	5	8.2	6.5	9.0	0.0	0.0
Mt Townsend Site 1 (Towns3)	14-18/2/84	100	3	300	1	0	5	3	9	1.7	5.7	20.3	0.0	0.0
Mt Townsend Site 2 (Saddle)	14-18/2/84	100	3	300	1	0	8	2	11	1.3	2.3	7.3	0.0	0.0
Totals		3015	94.5	9620	20	7	36	22	85	4.0	10.1	10.3	0.1	0.0

* Bp - ***Burramys parvus***, Mf - ***Mastacomys fuscus***, Rf-***Rattus fuscipes***, Asw-***Antechinus swainsonii***. Aa- ***Antechinus agilis***

APPENDIX 3

Appendix 3. Details of trapping results from this study (summarised in Table 2) * Bp are total individuals, other species are the maximum captures on any night.

Cluster#	Cluster	Boulderfield	dates	area ha	N# traps	nights	trapnights	Bp F	Bp M	Bp density	Mf	Rf	Asw	Aa
1	Gungartan	A	11-13/11/97	0.29	25	3	75	0	0	0.00	2	2	1	0
1	Gungartan	B,C,D,5	11-13/11/97,25-28/11/01	2.61	75	3	225	5	2	2.68	1	5	0	0
1	Gungartan Pass	2,3,4	2-5/12/01	0.91	40	4	160	0	0	0.00	0	3	0	0
1	Gungartan Pass	A	14-16/11/97	0.41	25	3	75	0	0	0.00	0	0	0	0
1	Gungartan Pass	B1-B6	14-16/11/97	0.90	25	3	75	0	0	0.00	0	0	0	0
1	Gungartan Pass	C,D	14-16/11/97	0.24	25	3	75	0	0	0.00	0	0	0	0
1	Gungartan Pass	E	2-5/12/01	1.26	50	4	200	2	2	3.18	0	2	1	0
2	White's R.	A1,B,C1,D	8-10/11/1997	1.01	88	3	264	2	1	2.98	0	0	0	0
3	Dicky Cooper	A	11-13/11/97	1.66	25	3	75	0	0	0.00	0	0	0	0
3	Dicky Cooper	B	11-13/11/97	0.69	25	3	75	0	0	0.00	0	0	0	0
4	Windy Ck	A1-A4	9-11/12/97	0.28	25	3	75	1	0	3.55	0	0	0	0
4	Windy Ck	B	10-11/11/97	0.08	6	2	12	0	0	0.00	0	0	0	0
4	Windy Ck	C	10-11/11/97	0.10	10	2	20	2	0	19.23	0	0	0	0
4	Windy Ck	E1,E2	11/11/1997	0.20	20	1	20	0	0	0.00	0	1	0	0
5	Anderson	A	13-14/12/97	0.39	50	2	100	0	0	0.00	0	0	0	0
5	Anton	A1+A2	13-14/12/97	0.24	18	2	36	0	0	0.00	0	0	0	0
5	Anton	B1+B2	13-14/12/97	0.16	8	2	16	0	0	0.00	0	0	0	0
5	Anton	C1-C3	13-14/12/97	0.20	20	2	40	0	0	0.00	0	0	0	0
5	Anton	D	13-14/12/97	0.19	25	2	50	0	0	0.00	0	1	0	0
6	Blue Lake	A1-A4	28-30/11/98	0.56	30	3	90	0	0	0.00	0	2	0	0
6	Blue Lake	B1-B7	28-30/11/98	0.47	15	3	45	0	0	0.00	0	0	0	0

APPENDIX 3

Cluster#	Cluster	Boulderfield	dates	area ha	N# traps	nights	trapnights	Bp F	Bp M	Bp density	Mf	Rf	Asw	Aa
6	Headley Tarn	A1	21-23/11/97	1.12	35	3	105	1	1	1.79	0	2	1	0
7	Byatts Camp	A1+B1	16-18/12/97	8.31	100	3	300	0	1	0.12	0	2	0	0
7	Lady Northcote	1	10/12/1997	0.31	25	1	25	1	0	3.21	0	0	0	0
7	Townsend	2	27-30/11/00	2.72	100	4	400	8	1	3.31	0	9	1	0
7	Townsend	3	16-17/12/97	1.10	120	2	240	1	1	1.82	0	0	0	0
7	Townsend	2AB	16-17/12/97	0.49	75	2	150	1	0	2.06	0	1	0	0
7	Townsend	4A-D	16-17/12/97	2.47	65	2	130	1	0	0.41	1	3	0	0
7	Townsend	Peak	27-30/11/00	2.20	50	4	200	14	2	7.26	1	2	1	0
7	Townsend	Saddle	9-12/12/98	2.78	50	4	200	8	1	3.24	0	2	0	0
7	Townsend	TA	9-12/12/98	1.00	25	4	100	1	0	1.00	1	2	1	0
8	Wilkinsons	A	16-17/12/97	1.12	100	3	300	0	0	0.00	0	1	0	0
8	Wilkinsons	B	16-17/12/97	0.49	75	3	225	0	0	0.00	0	0	0	0
8	Wilkinsons	C	16-17/12/97	0.13	25	3	75	0	0	0.00	0	0	0	0
9	Muellers	1	9-11/12/97	0.93	25	3	75	7	7	15.09	0	0	0	0
10	Kosciuszko	Kos Peak	5-8/12/98	0.53	25	4	100	9	4	24.71	0	1	0	0
10	Kosciuszko	northA-C	7-9/12/98	4.76	75	3	225	7	1	1.68	0	18	0	0
10	Kosciuszko	south A-C	3-6/12/98	4.46	100	4	400	11	4	3.36	0	19	0	0
11	Cootapatamba	w'fallA,B,C	12-14/12/97	0.71	45	3	135	0	0	0.00	1	0	0	0
11	Cootapatamba	X,Y,Z	12-14/12/97	0.74	60	3	180	1	1	2.71	0	6	1	0
11	Swampy Plain	A	4-7/12/00	0.50	25	4	100	2	1	6.04	0	6	0	0
11	Swampy Plain	B	4-7/12/00	0.30	35	4	140	3	0	9.97	0	1	1	0

APPENDIX 3

Cluster#	Cluster	Boulderfield	dates	area ha	N# traps	nights	trapnights	Bp F	Bp M	Bp density	Mf	Rf	Asw	Aa
11	Swampy Plain	C	12-15/12/00	0.82	50	4	200	0	0	0.00	0	1	0	0
12	Central Ramshead	A1,2	9-11/12/99	1.30	25	3	75	2	1	2.30	0	1	6	0
12	NS Ramshead	A	9-11/12/99	1.23	25	3	75	0	0	0.00	0	2	0	0
12	NS Ramshead	B	9-11/12/99	0.94	25	3	75	0	0	0.00	0	6	0	0
12	South Ramshead	A	11-13/3/99	1.53	25	3	75	0	0	0.00	0	1	2	0
12	South Ramshead	B	11-13/3/99	0.59	25	3	75	1	0	1.69	0	4	1	1
13	North Ramshead	A	12-15/12/00	0.37	10	4	40	0	0	0.00	0	0	0	0
13	North Ramshead	B	12-15/12/00	2.03	35	4	140	0	0	0.00	0	1	0	0
13	North Ramshead	C	12-15/12/00	0.50	30	4	120	0	0	0.00	3	0	0	0
13	Thredbo	A1 A2	9-11/12/99	0.64	25	3	75	1	1	3.15	0	6	1	0
13	Thredbo	B1	9-11/3/99	0.64	25	3	75	0	0	0.00	0	1	1	0
13	Thredbo	C1 - C4	9-11/12/99	1.39	25	3	75	0	0	0.00	0	5	0	0
14	Etheridge	A1	11-13/12/97	0.55	20	3	60	2	1	5.45	1	1	1	0
14	Etheridge	B1	11-13/12/97	0.26	25	3	75	0	0	0.00	0	4	0	0
14	Etheridge	C1+2	11-13/12/97	0.29	25	3	75	3	1	13.84	1	0	0	0
15	Merrits Ck	A1-A4	11-13/12/97	0.53	34	3	102	0	0	0.00	1	0	0	0
15	Merrits Ck	B1+B2	11-13/12/97	0.69	26	3	78	0	0	0.00	4	0	0	0
15	Snowy	A-D	11-13/12/97	0.56	50	3	150	0	0	0.00	0	0	0	0
16	Summit Rd	A-D	29/11-2/12/00	1.29	100	4	400	11	10	16.23	1	17	1	0
17	Charlotte Pass	Boys A-C	4-7/12/99	0.79	50	4	200	1	7	10.13	1	16	2	1
17	Charlotte Pass	Dam	3-5/12/01	0.24	25	3	75	2	3	21.28	0	11	1	0
17	Charlotte Pass	Main-ABCD	8-11/12/96	2.24	100	4	400	27	18	20.10	2	12	2	0

APPENDIX 3

Cluster#	Cluster	Boulderfield	dates	area ha	N# traps	nights	trapnights	Bp F	Bp M	Bp density	Mf	Rf	Asw	Aa
17	Guthries	8+9+11	12-14/12/97	0.69	50	3	150	1	1	2.89	0	1	1	0
17	Wrights Ck	A+B	5-7/12/97	0.37	50	3	150	0	2	5.36	0	7	0	0
18	Spencers Ck	A1	12-15/12/96	0.34	25	4	100	2	0	5.85	0	8	0	0
18	Spencers Ck	B	12-15/12/96	0.59	50	4	200	4	3	11.93	0	6	0	0
18	Spencers Ck	C1,C4	6-9/12/98	1.07	105	4	420	6	8	13.08	0	16	0	0
19	Paralyser 1	A1	28/11-1/12/01	0.39	35	4	140	6	1	17.95	0	4	0	0
19	Paralyser 2	AB1-3	10-13/12/96	0.90	50	4	200	9	3	13.33	1	7	0	0
19	Paralyser 3	A+B	28/2-3/3/01	0.64	45	4	180	2	0	3.13	0	3	1	3
19	Paralyser 3	C1-3	10-13/12/96	0.67	25	4	100	3	3	8.97	0	7	1	0
19	Paralyser 4	D1-D3	10-13/12/96	0.52	25	4	100	1	3	7.65	3	3	1	0
19	Betts Ck	2+3	4-6/12/97	0.25	20	3	60	0	0	0.00	0	1	0	0
20	Blue Cow	Area 13	19-21/12/00	0.86	25	3	75	1	1	2.33	0	4	0	0
20	Blue Cow	Area 7a	19-21/12/00	0.61	25	3	75	1	2	4.93	0	9	0	0
20	Blue Cow	BCPa,b	2-5/12/98	2.63	90	4	360	18	5	8.74	1	0	2	0
20	Blue Cow	BCSAL A,B	19-21/12/00	1.11	50	3	150	2	1	2.70	1	8	1	0
20	Blue Cow	LBC,UBC,A6	24-27/11/98	3.24	100	4	400	14	8	6.79	1	5	2	0
20	Guthega	A1, A2	15-17/11/89	0.38	25	3	75	6	1	18.67	0	9	0	2
20	Guthega	B	15-17/11/89	0.25	25	3	75	3	3	24.10	0	4	0	0
20	Guthega	BBMb	13-16/03/01	0.27	25	4	100	1	1	7.52	0	2	1	1
20	Guthega	BBWa,b	13-16/03/01	0.65	40	4	160	0	2	3.07	0	1	2	3

* Bp - *Burramys parvus*, Mf - *Mastacomys fuscus*, Rf-*Rattus fuscipes*, Asw-*Antechinus swainsonii*. Aa- *Antechinus agilis*

APPENDIX 4

High quality habitat at Mt Blue Cow (1700-1984m) in 1996: diverse *Podocarpus lawrencei* heathland overlaying deep boulders with a high component of small to medium sized rocks. This site was burnt in 2003. Photo, L. Broome.

The peak of Mt Blue Cow (this photo) and the peaks of Mt Townsend and Kosciuszko are unvegetated but can have high numbers of Bogong Moths, a favoured food item for the Mountain Pygmy-possum. L and R Broome with moth trap. Photo, M Schroder.

High quality habitat at Charlotte Pass on the slopes below Mt Guthrie (1750 – 1920m). Photo, L. Broome.

APPENDIX 4

H. Shi and W. Zhongming measuring rock structure among diverse *Podocarpus lawrencei* heathland at the Paralyser 1760 – 1900m (extends to 2054m on Mt perisher). Photo, L. Broome.

Mountain Pygmy-possum adult female trapped at the Paralyser. Photo by R. Plum and C. Corkran.

The steep western slopes of Abbott Ridge with Mt Townsend 2209m (left) and Abbott Peak 2159m (centre). Photo, I. Pulsford.

APPENDIX 4

Volunteers trapping on the western slopes of Mt Townsend. Note the large size of the rocks; densities of Mountain Pygmy-possums are low in these areas. Photo, L. Broome.

The peak 2228m (left) and western slopes of Mt Kosciuszko. This area can support high numbers of Mountain Pygmy-possums but annual numbers can be quite variable. Photo, L. Broome.

The Whites River boulderfields (1670 m) are bisected by a road and power line easement. Possum numbers were low here despite good habitat structure. Photo, M. Dawson.